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LOW COST WET ABRASIVE BLAST PROCESS FOR LEAD PAINT REMOVAL

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ABSTRACT

TRIDENT Refit Facility (TRF) has worked closely with vendors and local regulators to develop a wet abrasive blast paint removal process. This work was initiated when dry abrasive blast operations in their drydock were shut down due to the associated air emission requirements. This action directly affected the command's ability to accomplish its fundamental mission to refit ballistic missile submarines. TRF identified two vendors to help resolve the problem. The first vendor had developed a new system for wet abrasive blast. Introduced in the European market in 1984, the TORBO blast system was brought to the United States in 1992 when it was presented at a national conference of the Steel Structures Painting Council. It is used by Departments of Transportation in many states in the process of preserving bridges. The second vendor had developed an abrasive additive, Blastox, which reacts with the lead paint chips to create a waste product that can be designated as nonhazardous. The wet abrasive blast process developed was first used on the USS MICHIGAN (SSBN 727) hull. It is now routinely used whenever exterior hull paint removal is required. The most important outcome of this process development is that it will permit TRF to pursue work packages involving hull paint removal into the indefinite future.

1. INTRODUCTION

In parallel to the development of the TORBO system at TRF a closed loop, Ultra-High Pressure Water-Jet System (UHP WJS) for depainting large ships was developed as part of the U. S. Navy Advanced Technology Development (ATD) Program. This closed-loop system is capable of removing coatings from underwater hull areas using recycled ultra-high pressure water. The need for the system was initially addressed for the Navy by researchers at the David Taylor Research Center in Bethesda, Maryland. They found that high-pressure cavitating water jets offered the best alternative to abrasive blasting for underwater hull paint removal.[1] Later as higher pressures were implemented, it was found that the high pressure alone was sufficient to erode the paint. The UHP WJ System has proven itself successful in cutting the cost of depainting the hulls of several ships. Following a brief explanation of the two systems, the documented success of the TORBO system on the USS Michigan hull will be addressed. By keeping the system simple and capturing lead in the Blastox, the cost of depainting can be reduced to one fourth of that which was necessary to sand blast the hull of the USS Ohio (SSBN 726) using dry blasting and containment.

2. SYSTEM DESCRIPTIONS

This section explains the TORBO Wet Abrasive Blasting System and the Ultra-High Pressure Water-Jet System. In order to clearly understand the advantages and disadvantages of these systems, the reader must have a good understanding of the systems under comparison.

2.1 TORBO

The TORBO system consists of a pressure vessel assembly with loading hopper assembly, a control cabinet assembly and support components. A unique safety innovation only available with TORBO equipment is the Control Magnet. The Control Magnet is fastened to the wrist of the operator and functions to shut down the system if the operator looses control and the blasting hose begins whipping out of control. This significant improvement in the area of control, coupled with the unique design of the equipment which reduces airborne particulate, makes open air blasting possible again. Two other items of safety equipment that are required in addition to the standard personal protective equipment, are a respirator and protective coveralls, full-face air supplied respirators are required when below the maximum beam line.[2] These are required because of the high volume of mist containing paint particulate and Blastox. This wet abrasive system is much simpler than the UHP WJS. The simplicity of the design reduces the up front cost and the maintenance requirement. Although it is versatile in the types of abrasives that it can support, this system is restricted to dry docks which have a closed loop drainage system. Because the TORBO system does not have its own water reclamation system, it is restricted to dry docks with such a system.

2.1.1 PRESSURE VESSEL AND LOADING HOPPER ASSEMBLY

The pressure vessel is the primary component of the TORBO system. The loading hopper is used with the installed water pump for loading the abrasive into the pressure vessel. Water and abrasive are washed together through the hopper into the pressure vessel. As indicated, the abrasive does not have to be dry, but can be wet when loaded in the hopper. The vessel has a sealing disc that shuts against water pump pressure. The pressure of the vessel and the flow rate of blast water are controlled at the control panel.

2.1.2 CONTROL PANEL

The control panel consists primarily of gages and valves to regulate the air and water pressures and flow rates. The system is activated at the nozzle when the Control Magnet is placed in the receptacle on the 3-Way Remote Control Switch. The switch is turned off by removal of the Control Magnet from the switch. The three blasting options are Blast Mode, Blowdown Mode and Washdown Mode. Although this system is much simpler than the UHP WJ System, the operators require significantly less training in the proper control settings and blasting methods.

2.1.3 BLAST MEDIA

The TORBO unit may be used to blast with various media. TRF uses copper slag mixed with 20% Blastox. Blastox is a cement-like material containing calcium silicates and calcium aluminates. The TDJ Group, Inc. has patents pending on the proprietary chemistry of this mix that was introduced in 1991 as a chemical stabilizer. The environmental Protection Agency, EPA, and the Naval Sea Systems Command have both approved of Blastox for unrestricted use without hazardous waste treatment permits. It is the standard on which the current Best Demonstrated Available Technology, BDAT, as reported on the EPA RCRA Hotline, is based. Furthermore, a blend of abrasive media with 15% Blastox used at 8 lb./sq. ft. will reduce leachable lead levels from as high as 100 mg/liter to below 5 mg/liter (5 ppm), which is the EPA limit. The blast process is safe and has been proven to consistently stay well below the 0.030 mg/CM^3 OSHA action level.

Although adding Blastox to the abrasive media adds at least $60/ton to the cost, the savings in hazardous waste disposal costs can be as much as 75%. This cost savings is an important factor when added to the environmental benefit of lead encapsulation. Because the wet TORBO - Blastox mix when sprayed against the hull leaves a mist, the mist needs to be washed off the hull at least shiftly. Pressure washing the hull adds to the facility's water treatment costs, but ensures that the hull's surface is not adversely affected by the Blastox film.

2.2 ULTRA-HIGH PRESSURE WATER-JET SYSTEM

The closed-loop, Ultra-High Pressure Water-Jet System, UHP WJS, is composed of three major subsystems: a nozzle mounted on a six axis manipulator, a high pressure hydro-pump, and a mobile water recovery subsystem. Ultra-high pressure water from the pump is sprayed onto the hull, with sufficient force to displace the paint. Paint and primer are removed, leaving a near white metal finish. The loose particles of paint and primer are vacuumed into the return line of the mobile recovery unit and processed out as a sludge. The water in that return line is processed for reuse. The goal is to have 100% recovery of the process water and to recirculate that water to the maximum extent possible.

2.2.1 END EFFECTOR SUBSYSTEM

This is the focal point of the total system. It is in this robotically controlled subsystem that the six inch waterjet nozzle is mounted and rotated for transversing a 52 inch by 78 inch area. The waterjets of the nozzle are effective in fully removing, salt, rust, grease, and various paint systems. The nominal pressure of the water at the nozzle is 36,000 psi. Industry standard presently sets 25,000 psi as the lower limit for ultra-high pressure water jetting.

2.2.2 HIGH PRESSURE PUMP SUBSYSTEM

The high pressure pump subsystem consists of dual, intensifiers mounted on a trailer. These Hydro-Pac pumps deliver a non-pulsating flow of water to the supply lines. Experimental research showed that optimum paint removal rates could be achieved by evenly distributing the water energy at the highest achievable pressure. Associated water lines, hoses, valves and fittings were designed to minimize pressure losses. The water supply is provided by the recovery system. The minimum specifications for water pressure and flow rate are 36,000 psi at 10 gpm in order to achieve the desired removal rates. These specifications drove the design requirement to a hydraulic pumping system powered by a 325-horsepower diesel motor.

2.2.3 MOBILE RECOVERY SUBSYSTEM

This subsystem consists of the mobile vacuum recovery unit that recovers the water from the blast head and processes it for reuse. The effluent containment device surrounding the water-jet blast nozzle has a strong vacuum that is capable of containing all of the process water and paint chip residue and preventing it from falling to the dock floor. The mobile recovery unit has various interconnected subsystems, such as the diesel-powered electric generator, air compressor, vacuum unit, liquid/solid separator, water recovery/recirculation system, and deionization system, all mounted within the utility trailer. The liquid/solid separator removes suspended particulate from the effluent stream prior to entering the water reclamation unit. In the reclamation unit the water is processed through a centrifugal separator and several purification filters before it is deionized. The mobile recovery system segregates, filters, purifies, and deionizes prior to return to the nozzle through the high pressure pump. The requirement for the hydro-pump to need minimal water filtration drove the criterion for accepting only water with particles greater than one micron.

3. PERFORMANCE ASSESSMENT

3.1 PAINT REMOVAL

The UHP WJS has been used on several hulls by Puget Sound Naval Shipyard (PSNS). It has been evident that the expected stripping rate and time requirement to set up the end effector in each subzone has not been realized. At 6.5 minutes per subzone, it was hoped that 200 subzones could be depainted in a 10 hour shift. This would amount to 3200 sq. ft. per shift with the 48 inch by 48 inch manipulator frame. With the 52 inch by 78 inch manipulator frame, the most productive shift for the UHP WJS wrought only 951 sq. ft. of depainted surface. The TORBO system had a high paint removal rate when depainting the USS Michigan. The nozzles were capable of blasting 120 to 150 sq. ft. per hour. When six blast nozzles were used in parallel, the TRF paint team could depaint in one hour the same area that it takes one shift to depaint with the UHP WJS.

3.2 COMPARISON OF SURFACE FINISH

Both the UHP WJS and the TORBO unit are capable of cleaning the surface of paint, sulfates and chlorides and should be used with a rust inhibitor. Dry abrasive blasting tends to trap contaminants in the crevices as the blast material impinges on the surface.[3] Howlett and Dupuy have also shown some other facts regarding the UHP WJS process that would indicate that an optimum surface would be obtained with the use of garnet injected into the jet stream. For example, water jetting alone will not create or change the surface profile of the blasted area. The visual appearance is not that of the white metal finish left by abrasive blasting. If the area has rough mill scale, the surface may still need to be prepared by hand prior to painting to ensure an adequate surface finish. Since the UHP WJS process does not leave a surface profile as does the abrasive blasting process, it should be used only on materials that have been previously blasted.[4]

3.3 WORK SCHEDULE AND MANNING

The UHP WJS is typically operated for two ten hour shifts per day for six days per week. The minimum work crew consisted of one paint supervisor, two equipment operators, and two maintenance mechanics. The crew was augmented with one additional equipment operator per shift to assist in guiding the blast frame onto the hull and reduce operator fatigue. Painters at TRF, Bangor worked two 12 hour shifts, around the clock for 14 days. To support six blasters in operation, TRF purchased eight TORBO units. Each shift had six painters who stripped the hull with their individual blast nozzles. Additionally, there averaged four support personnel for delivering and filling hoppers with blast media and cleaning up the grit as the stripping progressed. The support personnel were also used for cleaning the TORBOs as the cement-like Blastox solidified in vessel. The team was well coordinated and factory trained in order to support this type of accomplishment in such a short time frame.

3.4 MAINTENANCE AND PERFORMANCE IN THE INDUSTRIAL ENVIRONMENT

Because of the complexity of the UHP WJS, there are many subsystems within systems allowing ample opportunity for equipment malfunction or shutdown for repair or preventive maintenance. The list below documents some of the difficulties with this highly complex system over the past year of evaluation by PSNS:

Fasteners broken/loosen during shipping	Sheared bolt on intensifier
Diesel for air compressor failed to start	Dri-prime pump clogged with paint chips
Conductivity meter pegged high	Dead battery on intensifier support diesel
Micro separator centrifuge required cleaning	Shaft seal failure on six nozzle drive's motors
Lifting lug crack needed repair	Nozzle rotation problem limits travel speed

Centrifuge filled with paint chips	Transporter cable needed repair
Paint chip barrel filled with water	Spurious shutdown of end effector drives
Leak in swivel body shaft seal	Loose bearing on frame tilt mechanism
Intensifier hydraulic cylinder leak	Broken suction piping
Intensifier check valve failures	Make-up water pump did not cycle on to fill tank
Boom failed to extend	Z-axis retraction repair
Proximity switch leak on intensifier	Failed UHP water lines (13 hoses)

System improvements are gradually increasing the removal rate of this developing technology.

The TORBO system is shutdown every 45 to 60 minutes for replenishment of the blast media. The workers would prefer a system that let them blast for at least 150 to 200 minutes before having to refill the vessel. The nozzles used for blasting the USS Michigan experienced some erosion which has occurred after a longer period when blasting with river sand.

3.6 USS MICHIGAN DEPAINTING PROJECT

The first sand blasting ever accomplished in the TRF dry dock was the initial use of the TORBO Wet Abrasive Blasting System to depaint a submarine hull. Although documents vary slightly on the details, Table 1 shows some of the documented results from using six TORBO units to depaint the entire hull of the USS Michigan (SSBN 727).

Area Depainted	65,000 sq. ft.
Time Frame / Schedule	14 days / 2 twelve hour shifts
Deployment	6 of 8 TORBOs stripping
Depainting Rate	120 to 150 sq. ft. / hr
Blast Media Rate	2 to 4 lb. / sq. ft.
Blast Media	Copper slag with 20% Blastox
Water Rate	5 gallons / hr / machine
Inhibitor	1:250 Rust-Lick-B
Depainting	3464 man hours
Media Disposal	96 tons @ $54/ton = $5184

Table 1 TORBO Wet Abrasive Blasting System usage on at TRF, Bangor

The combination of more efficient blasting with the TORBO and the chemical stabilization of the lead in the paint chips with the elimination of the requirement for full containment saved TRF 10,000 man hours and nearly $500,000 dollars.[5]

4. COST COMPARISON

The cost comparison performed in this section was based on Trident submarines. The Trident submarine was chosen since there were recent projects which have accomplished the task of complete depainting and hull preservation as part of the Engineered Overhaul. The approximate hull area to be depainted does affect some of the other factors in the cost comparison. Figures for the dry abrasive blasting of the USS Ohio were obtained from Job Order - Key Op charges and a broader cost comparison being performed in the Industrial Engineering and Planning Division [6]. The data for the TORBO Wet Abrasive Blasting of the USS Michigan is provided by the Trident Refit Facility. In the case of the labor charges, the 4040 man hours to TORBO

blast the USS Michigan were separated into the various categories based on good technical judgment. The total labor charge of 4040 man-hours, however, remains the same. Data from the first two UHP WJS projects, the USS Leftwich and the USS Paul F. Foster, were used to extrapolate and calculate rate and cost data. While the performance data was obtained in fiscal years 1993 through 1995, the cost data for labor rate, utilities, abrasive media, and waste disposal are in fiscal year 1996 rates.

4.1.1 COST COMPARISON DETAIL

Table 2: Dry Abrasive Blasting Vs. UHP WJS and TORBO

	Dry Abrasive	UHP WJS	TORBO
CONTAINMENT			
Manuf/Install/Remove	1500 man-day	N/A	N/A
Labor	$700,500	$0	$0
Fabric Cost	$17,500	$0	$0
Containment Total	$717,500	$0	$0
PAINT REMOVAL			
Labor in Open Areas			
Removal Rate per Nozzle	261 sq. ft./hr	204 sq. ft./hr	140 sq. ft./hr
Number of Nozzles	6	2	6
Percent Time Stripping	14.5%	20.0%	27%
Number of Blasters	6	4	6
Number of Support People	3	2	6
Dry Abrasive Blast Labor	25 sq. ft./man-hr	N/A	N/A
Labor Near Protrusions			
Removal Rate per Nozzle	N/A	40 sq. ft./hr	N/A
Number of Nozzles	N/A	6	N/A
Percent Time Stripping	N/A	10.0%	N/A
Number of Blasters	N/A	6	N/A
Number of Support People	N/A	2	N/A
Man-Days for Paint Removal	324	916	360
Depaint Labor Total	$151,300	$427,800	$168,120
Blast Material			
Abrasive Usage Rate	12.5 lb./sq. ft.	N/A	2.6 lb./sq. ft.
Abrasive Usage	406 tons	N/A	84 tons
New Abrasive Cost	$70/ton	N/A	$205/ton
Total Abrasive Cost	$28,500	N/A	$17,220
Number of Manlifts Required	N/A	N/A	6 for 2 weeks
Manlift Rental Cost	N/A	N/A	$1200/week
Total Manlift Rental Cost	N/A	N/A	$14,400
Blast Material Total	$28,500	N/A	$31,620

Utilities			
Compressed Air Required/Nozzle	250 cfm	N/A	190 cfm
Total Hours of Nozzle Time	249 hrs	N/A	454 hrs
Total Compressed Air Cost	$4,100	N/A	$5700
# of Dust Collectors	2	N/A	N/A
Dust Collector Motor Size	75 hp	N/A	N/A
Dust Collector "On" Time	289 hrs	N/A	N/A
Total Electricity Cost	$1,370	N/A	N/A
Diesel Fuel/Blast Hour	N/A	25.56 gal/hr	1.5 gal/hr/manlift
Total Diesel Fuel Cost	N/A	$6,210	$470
Utilities Total	$5,470	$6,210	$6,170
Maintenance			
Maintenance Ratio	0.30	0.20	0.07
Total Maintenance Man-hours	74.7 hrs	70.4 hrs	32 hrs
Maintenance Materials	$0.05/sq. ft.	$0.50/sq. ft.	$0.05/sq. ft.
Total Maintenance Materials	$3,250	$32,500	$3,250
Maintenance Total	$7,610	$36,610	$5,120
Waste Disposal			
Abrasive Clean-up			
Bulk Abrasive Removal MH	700 hrs	0	264 hrs
Clean-up Total	$40,860	$0	$15,411
Blast Debris			
Abrasive Disposal Cost	$390/ton	N/A	$54/ton
Paint Chip Disposal Cost	N/A	$2.08/lb.	N/A
Paint Chip Weight	0.375 lb./sq. ft.	0.375 lb./sq. ft.	0.375 lb./sq. ft.
Amount of Waste Generated	418.4 tons	12.2 tons	96 tons
Blast Debris Waste Total	$163,200	$50,700	$5184
Waste Water			
Water Usage Rate	N/A	N/A	5 gal/hr
Actual Washing Time	N/A	N/A	288 hr
Hull Rinse Water	N/A	N/A	2800 gal
Total Water Used	N/A	N/A	5120 gal
Dry Dock Rinse Waste Tot	$0	$0	$770
TOTAL PROJECT COST	$1,114,450	$521,320	$232,400

Approximate Duration	17 days	39 days	14 days
Containment Cost	$11.04/ sq. ft.	$0	$0
Blast Rate	226 sq. ft./man-day	71 sq. ft./man-day	191 ft2./man-day
Blast Material Cost/ sq. ft.	$0.44/ sq. ft.	$0	$0.49/ sq. ft.
Disposal Cost/ sq. ft.	$3.14/ sq. ft.	$0.78/ sq. ft.	$0.21/ sq. ft.
Project Cost/ sq. ft.	$17.15/ sq. ft.	$8.02/ sq. ft.	$3.35/ sq. ft.

Area Blasted = 65,000 sq. ft.
Labor Rate = $467/man-day
Water Processing Cost = $0.15/gal
Percent "Open" Area = 85%
Compressed Air = $0.0011/cf.
Cost of Electricity = $0.0423/kw-hr
Cost of Diesel Fuel = $0.69/ga

4.1.2 COMMENTS ON COST COMPARISON DATA

The containment labor was the actual charged labor and the fabric cost was calculated based on current fabric prices. It was assumed that the staging that supports the containment is part of the ready inventory normally available at a naval repair facility, so the cost of the staging was not included. No containments are necessary for the UHP WJ System because of its design for complete water recovery. Because of the ability of the Blastox to encapsulate the lead when TORBO blasting, no containment is necessary in this case either. If the project needed to do concurrent work in the dry dock, that containment would be an additional cost. If an inert abrasive were not readily available, some dry docks could require partial containment to prevent the abrasive from entering the dry dock drains. This cost was not taken into account since the TRF has a water treatment facility and the PSNS dry docks are being retrofitted with special drain piping that will also allow water recovery. Also included was the installation of temporary facilities such as lighting and breathing air associated with dry abrasive blasting in containments. It was also assumed that these temporary facilities were available at the shipyard and were not purchased for this project.

On this project it was assumed that for the use of the UHP WJS that 85% of the areas were assessable with the manipulator frame. The inaccessible areas are depainted with three smaller hand held nozzles that can be connected to the water reclamation system. The data for the hand-held attachments is estimated, since there has been limited use of these accessories to date. The open area removal rate is based on a 1.5 inch per second automated travel speed. The percent stripping time for the UHP WJS is unfortunately much lower than was anticipated by the designers and the operators, but reflects what has been achievable to date.

For the dry abrasive blasting and the TORBO blasting, the percent stripping time reflects that which has been achieved. In these cases the lower rate has more to do with personnel endurance than material condition.

The dry blast grit was copper slag. The abrasive used by the TORBO system was copper slag with 20% Blastox. Other abrasives may have a greater or lesser removal efficiency, but would provide similar results for comparison. Note that the manlifts used to reach the hull are considered a material cost in this section. These were needed only by the TORBO blasters. Although manlifts are usually available with advanced notice in most shipyards, the cost was included here since the UHP WJS is purchased with the transporter.

The utility figures were based on Public Works Center information provided in the cost analysis for PSNS[7]. The UHP WJS is self powered by its own generator and compressor, hence diesel fuel is the only utility.

While the maintenance ratio is estimated for the dry blast and wet blast cases, the actual data for the UHP WJS is used. The notional maintenance ratio was used to extrapolate the costs from small depainting projects to the larger Trident depainting project. The unproductive man-hours that accumulate during maintenance periods is included in the labor figures since it effects the percent stripping time. Since a maintenance man already supports the UHP WJS, the maintenance ratio is lower than if compared equally to the other methods.

Waste handling and disposal vary significantly among the three processes. If the project was removing only lead free paint, the disposal costs would be drastically different. The dry grit disposal cost would be reduced to $22,600 from $163,200. If the paint chip residue in the 55 gallon drums of the UHP WJS were considered industrial waste, the disposal cost would be much less. Instead of costing $2.08/lb., the disposal cost would be about $1.49/lb. The nationwide disposal costs vary greatly based on location and availability of landfills.

The actual duration of the projects varied based on the resource support that the depainting team received from the rest of the project. The team required to erect the containment for dry blasting needs is larger when the time in the dock is shorter. The 17 day duration is shorter than that accomplished on the USS Ohio because there were other factors involved. For this comparison, it was assumed that 30 men per shift from various trades were available for building the containment. The containment installation team would begin three days prior to the depainting and continue through the depainting process until two days after the depainting was complete. The sand blasting process would last 12 days, if continued for three shifts per day with the nine man team. For the UHP WJS, the 39 day duration was based on the stripping rates using two systems with either two or six nozzles depending on proximity to protrusions. The 14 day duration was actually accomplished at the TRF by the USS Michigan depainting team using the TORBO system.

5. CONCLUSIONS

The cost comparasion above does not include the capital outlay for basic abrasive blast equipment. The UHP WJ system is approximately $1,300,000 per unit. The analysis above is based on depainting rates requiring the use of two units. Eight sets of TORBO equipment were purchased by TRF for approximately $250,000 total. The cost of the UHP WJ system is expected to decrease with expanded use. TRF is already scheduled to depaint six more Trident submarine hulls. It is clear that use of the TORBO system will provide savings of approximately $4,000,000 while protecting the environment.

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